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URS 638-2

STUDY OF FACTORS INFLUENCING REMEDIAL MOVEMENT

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Submitted to  
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Myron B Hawkins

17 April 1964

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17 April 1964

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by

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Submitted to  
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## FOREWORD

The material for this report was first prepared in 1961 when the author was an employee of the Institute of Engineering Research of the University of California. The work was performed as part of an Office of Civil Defense and Mobilization contract that concerned investigations of radiological defense operations. A review of the available literature on peripheral countermeasures confirmed the author's view that with a slight revision and clarification of the material, this report provided a contribution to the knowledge in the general subject area, and a wider distribution of the information was desirable. Mr. William J. Lacy, the Office of Civil Defense Project Coordinator, has concurred.

~~ABSTRACT~~

The feasibility of remedial movement, i.e., transfer of people from inadequate fallout shelters to areas providing greater protection, was investigated. The study took into account fallout arrival time, reference radiation intensity, shelter or refuge protective factor, and travel time. Primary payoff conditions were defined in terms of reduction of radiation casualties.

Within the limitations imposed by the conditions of the study, certain general conclusions were drawn:

1. As might be expected, the maximum opportunities for payoff are related to refuges having lower protection factors, i.e., less than 10.
  2. Maximum payoff conditions are related to fallout arriving at early times.
  3. Maximum payoff conditions generally involve reference radiation intensities of 350 r/hr or greater, with the upper limit of about 2000 r/hr.
  4. For one-hour arrivals (i.e., when fallout arrives at about one hour after detonation), the maximum allowable travel time for maximum payoff is about 1.3 hours.
- ~~ABSTRACT~~

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## STUDY OF FACTORS INFLUENCING REMEDIAL MOVEMENT

## INTRODUCTION

One of the measures suggested for the reduction of fallout radiation casualties is postattack remedial movement<sup>1/</sup>. This countermeasure is defined as the transfer of people from "refuges" (areas where fallout radiation protection is less than a factor of 100) to areas providing greater protection. The movement would be performed in the period following fallout deposition and its object would be to reduce the radiation hazard to those persons not having adequate protection. The purpose of this study is to investigate and designate those radiological and operational situations for which remedial movement is technically feasible and worthwhile, as well as those situations in which remedial movement is unnecessary or unprofitable.

## EXPOSURE CRITERIA

Remedial movement has been assumed, for the purposes of this study, to be primarily a "life-saving" countermeasure; i.e., its purpose is to reduce the probability of death. Obviously, remedial movement can also be considered useful if it reduces the probability of injury. Although the relationship between radiation injury and exposure is controversial, some criteria are needed for analytical purposes. The following dose-effects criteria were selected somewhat arbitrarily for use in this study:

- 100r in less than two weeks - no illness,
- 200r in less than two weeks - a few people ill,
- 400r in less than two weeks - many ill, less than 50% mortality,
- 600r in less than two weeks - all ill, many deaths, few survivors.

These criteria, selected prior to the publication of the recommendations of the National Committee on Radiation Protection for emergency exposure<sup>2/</sup>, are in essential agreement with the Committee findings. The dose-effects cited above are approximately the same as those given for "brief, whole-body, gamma-ray" exposures (table 6.4, p. 70, of ref. 2). Since the above criteria cover exposure periods ranging from "brief" (a few seconds to four days) to two weeks, the effects should

be less than those stated above for the two-week exposures. In this sense, the criteria are conservative.

#### CALCULATIONS

The dose to people subjected to remedial movement consists of three components: 1) the dose received in the refuge before evacuation, 2) the dose received during the actual transfer, and 3) the dose received at the secondary location. To obtain an indication of the worth of remedial movement, the movement dose can be compared to the dose that would have been received if the person had chosen to remain in the refuge for, say, 14 days. The basic case studied herein was the movement in a vehicle from a refuge across the fallout area to an uncontaminated or decontaminated area. Only the first two dose components of the three cited above were calculated since the dose after movement would be negligible.

$$D_r \text{ (dose in refuge)} = d_f(t, t_a) \cdot I \cdot \frac{1}{P}$$

where  $d_f(t, t_a)$  = dose factor, i.e., dose in an exposed location from time of fallout arrival to any given time  $t$ , based on a reference intensity of 1 r/hr at one hour. Different dose factors are used herein for three different fallout arrival times,  $t_a$ ,

$I$  = reference intensity or dose rate of the fallout radiation, i.e., r/hr, corrected to one hour after detonation,

$P$  = protection factor of the refuge or shelter.

$$D_m \text{ (dose during movement)} = [d_f(t_3, t_a) - d_f(t_2, t_a)] \cdot I \cdot \frac{1}{P_v} \cdot C$$

where  $t_2$  and  $t_3$  = respectively the time movement is started and the time movement is completed (i.e., the time of exit from the contaminated area). Therefore,  $(t_3 - t_2)$  is the travel time,

$P_v$  = protection factor of the vehicle,

C = dose correction factor to compensate for the decrease of radiation intensity as the fall-out area is traversed.

$$D_t \text{ (total remedial movement dose)} = D_r + D_m.$$

#### CONDITIONS STUDIED

I (reference intensity, r/hr at 1 hour): 100, 300, 1000, 3000, 10,000 r/hr each for  $t_a$  = 1 hour, 6 hours, and 11 hours.

P (protection factor of refuge): 3, 6, 10, 20, 50.

$P_v$  (protection factor of vehicle): 2.

C (fallout field transit correction): 1/2.

$(t_3 - t_2)$  (travel time): 1/4, 1/2, 1, 2, 3, 4 hours.

$t_2$  (go-time): was determined for various combinations of P and  $(t_3 - t_2)$  on the basis of the equation:

$$t_2 = 0.6 P (t_3 - t_2).^*$$

However, since the dose predictions are dependent on knowledge of the reference radiation intensity, "go-time" was assumed never to be earlier than the time that fallout had ceased falling. These times were 1-1/2, 7, and 13 hours for fallout arrival times of 1, 6, and 11 hours, respectively. With the exception of the 1-1/2 hour cessation time, the "go-time" was

---

\* This equation gives the "go-time" for which the sum of the shelter dose and the movement dose is a minimum. The equation was originally developed by Brooks et al<sup>3/</sup> and adopted for operational use by the California Disaster Office<sup>4/</sup>.

rounded off to the nearest hour. These values are given in table 1.

The total number of computations was reduced by introducing limits based on the exposure criteria previously established. The limits are as follows: 1) if the refuge dose in 14 days is 100r or less, there is no need for remedial movement; 2) if the remedial movement dose,  $D_r + D_m$ , is greater than 600r, there is no obvious justification for remedial movement. Therefore, for cases in which either  $D_r$  or  $D_m$  is greater than 600r, no calculations were made.

#### FALLOUT DOSE DATA

Table 2 presents dose factors for the chosen arrival times. The numbers given are the dose in roentgens that will be received in an exposed location between the time of fallout arrival  $t_a$  and some later time  $t$ , for a reference radiation intensity of 1 r/hr\*. The dose during fallout arrival was established by numerically integrating empirical intensity curves. The dose after the arrival period is based on intensity-time data derived for fission product mixtures plus induced activities.

#### RESULTS

The results of the computations are shown on figures 1, 2, 3, 4, and 5, which correspond to refuge protection factors of 3, 6, 10, 20, and 50, respectively. Each figure is subdivided into separate graphs for the three arrival conditions. The figures may be interpreted as follows. Referring to figure 1 for a protection factor of 3 and a 1-hour fallout arrival:

1. A 600r refuge dose (in 14 days) occurs when the reference intensity is about 520 r/hr. A 400r 14-day refuge dose occurs at a reference intensity of about 350 r hr.

---

\* Reference radiation intensity, often called standard intensity, is the dose rate obtained by extrapolating the dose rate at any time to that at one hour after detonation.

$t_3 - t_2$	P, protection factor				
	3	6	10	20	50
1/4	0.45/1.5	0.9/1.5	1.5/1.5	3/3	7.5/8
1/2	0.9/1.5	1.8/2	3/3	6/6	15/15
1	1.8/2	3.6/4	6/6	12/12	30/30
2	3.6/4	7.2/7	12/12	24/24	60/60
3	5.4/5	10.8/11	18/18	36/36	90/90
4	7.2/7	14.4/14	24/24	48/48	120/120

First value - as calculated.

Second value - as rounded off or limited by fall-out cessation time of 1-1/2 hours.

Note: Values given apply to  $t_3 = 1$  hour. For  $t_3 = 6$  and 11 hours,  $t_2$  was not less than 7 and 13, respectively.

Table 1. "Go-time,"  $t_2 = 0.6 P (t_3 - t_2)$

$t$ (hr)	$t_a=1$	$t_a=6$	$t_a=11$	$t$ (hr)	$t_a=1$	$t_a=6$	$t_a=11$
1.5	0.467	-	-	28	2.50	1.10	0.708
2	0.725	-	-	29	2.52	1.11	0.726
3	1.06	-	-	30	2.53	1.13	0.743
4	1.29	-	-	31	2.55	1.15	0.760
5	1.45	-	-	32	2.57	1.16	0.776
6	1.58	-	-	33	2.58	1.18	0.791
7	1.69	0.286	-	34	2.60	1.19	0.806
8	1.78	0.375	-	35	2.61	1.21	0.820
9	1.86	0.452	-	36	2.63	1.22	0.834
10	1.92	0.519	-	37	2.64	1.24	0.847
11	1.98	0.579	-	38	2.65	1.25	0.860
12	2.04	0.632	-	39	2.66	1.26	0.872
13	2.08	0.679	0.291	40	2.68	1.27	0.885
14	2.12	0.718	0.329	41	2.69	1.28	0.896
15	2.16	0.755	0.367	42	2.70	1.30	0.908
16	2.20	0.792	0.404	43	2.71	1.31	0.919
17	2.23	0.827	0.439	44	2.72	1.32	0.930
18	2.26	0.859	0.471	45	2.73	1.33	0.940
19	2.29	0.889	0.501	46	2.74	1.34	0.950
20	2.32	0.918	0.529	47	2.75	1.35	0.960
21	2.35	0.944	0.556	48	2.76	1.36	0.970
22	2.37	0.969	0.581	49	2.77	1.37	0.980
23	2.40	0.993	0.605	50	2.78	1.38	0.989
24	2.42	1.02	0.628	51	2.79	1.39	0.998
25	2.44	1.04	0.649	52	2.80	1.40	1.01
26	2.46	1.06	0.670	1 wk	3.27	1.87	1.48
27	2.48	1.08	0.689	2 wk	3.50	2.10	1.71

Table 2. Dose Factors  $d_f(t, t_a)$ , i.e., Fallout Radiation Dose in Roentgens From Time of Arrival  $t_a$ , to Given Times  $t$ , Based on 1 r/hr Reference Intensity

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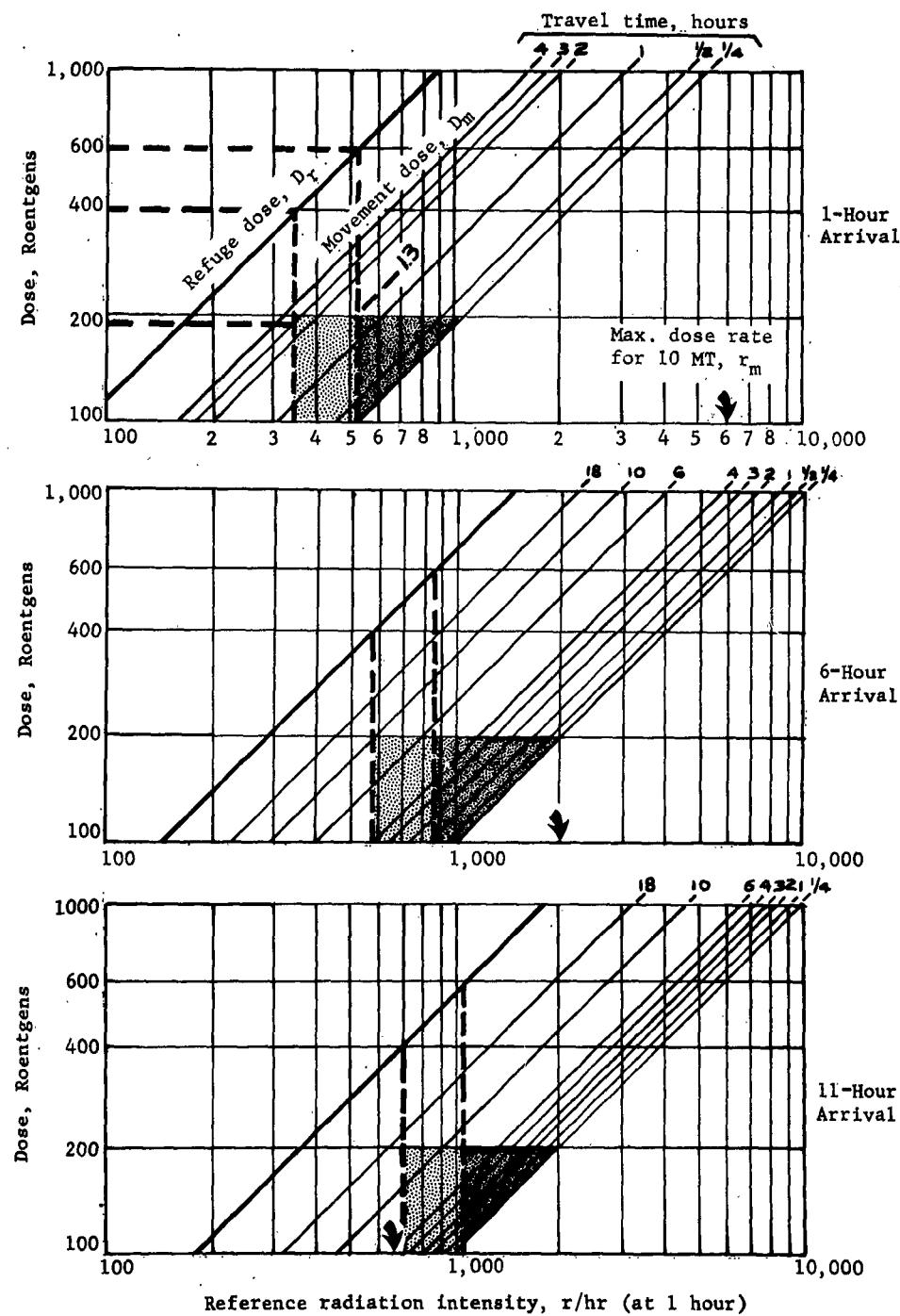


Figure 1. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 3

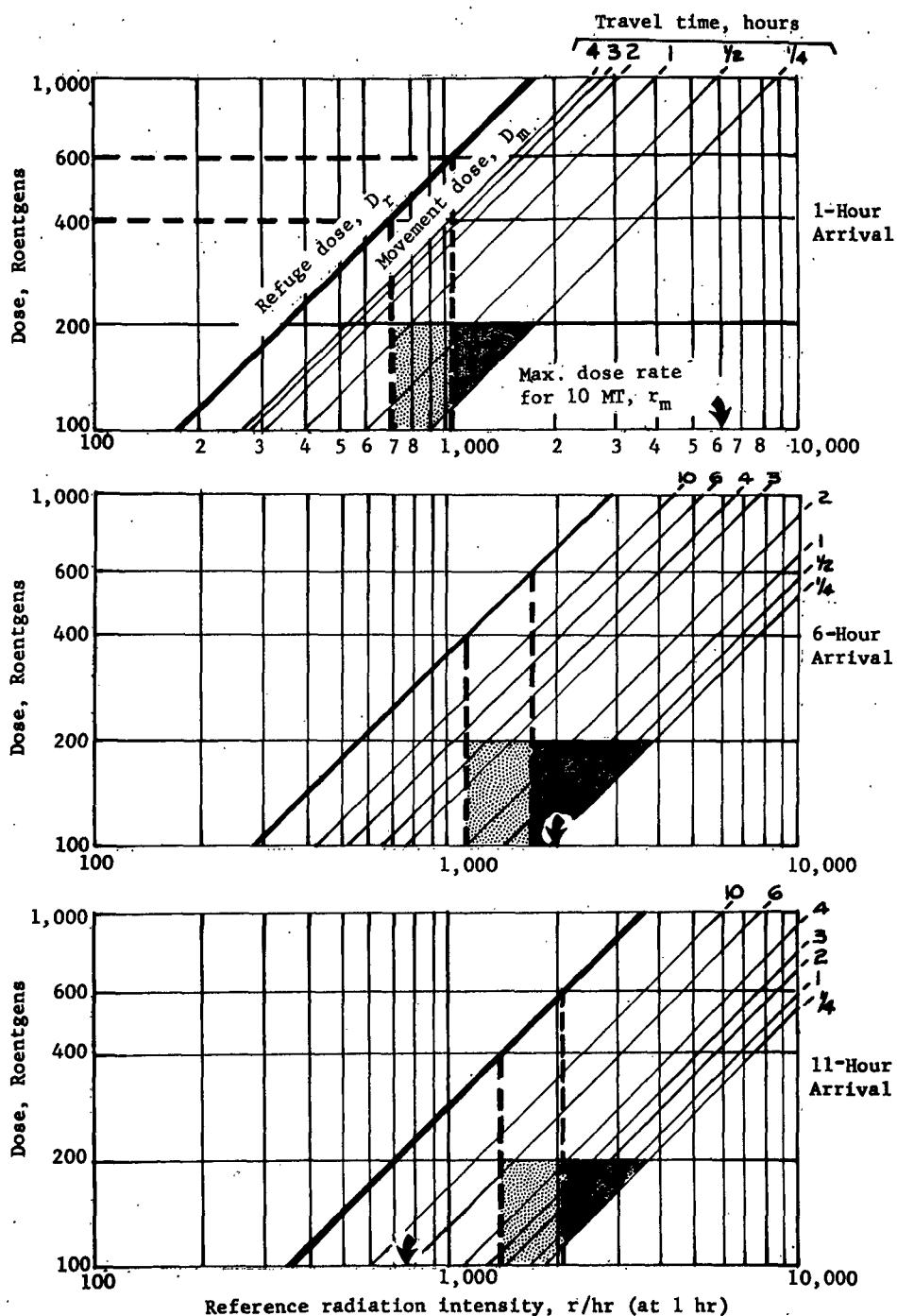


Figure 2. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 6

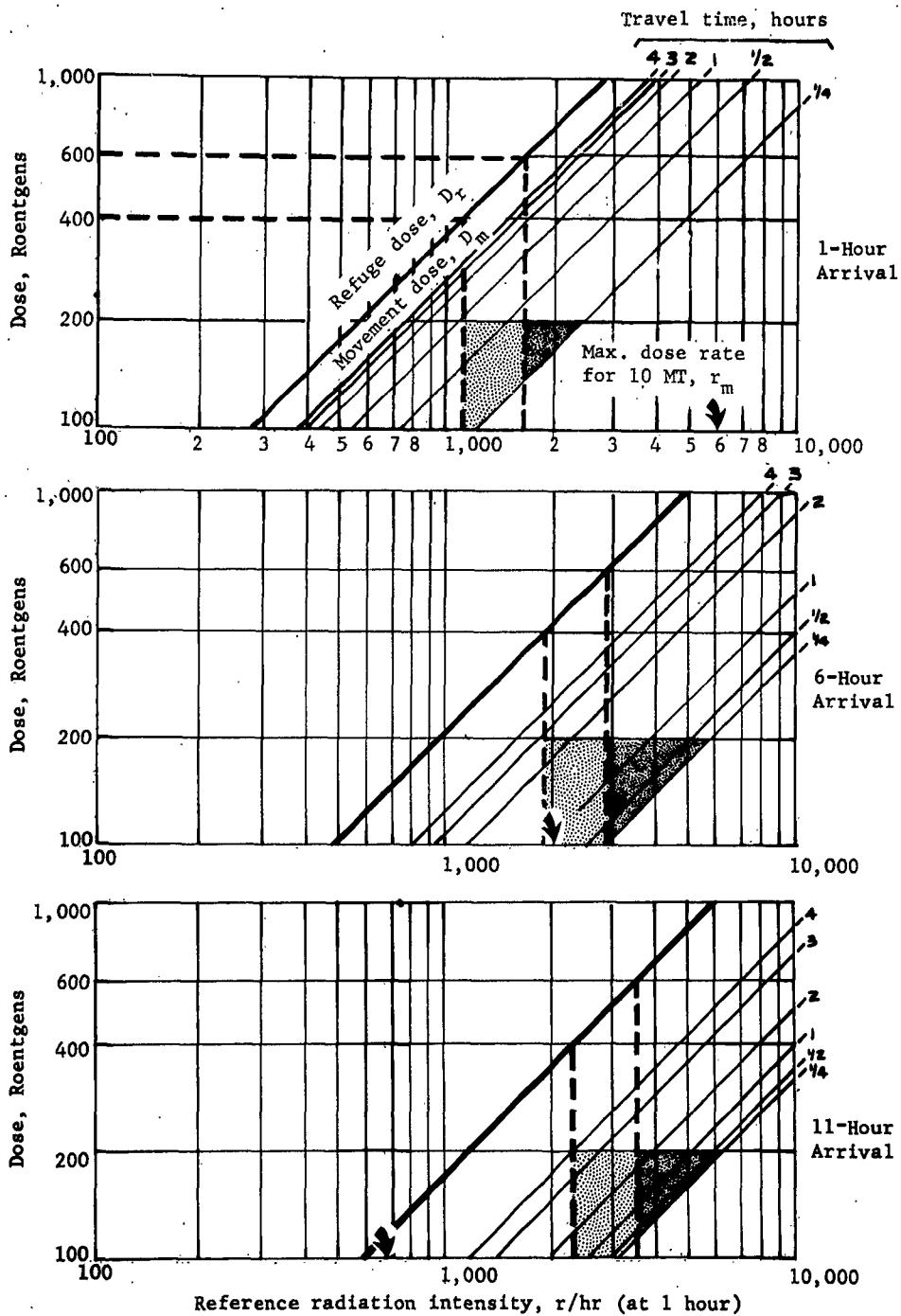


Figure 3. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 10

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Travel time, hours

10

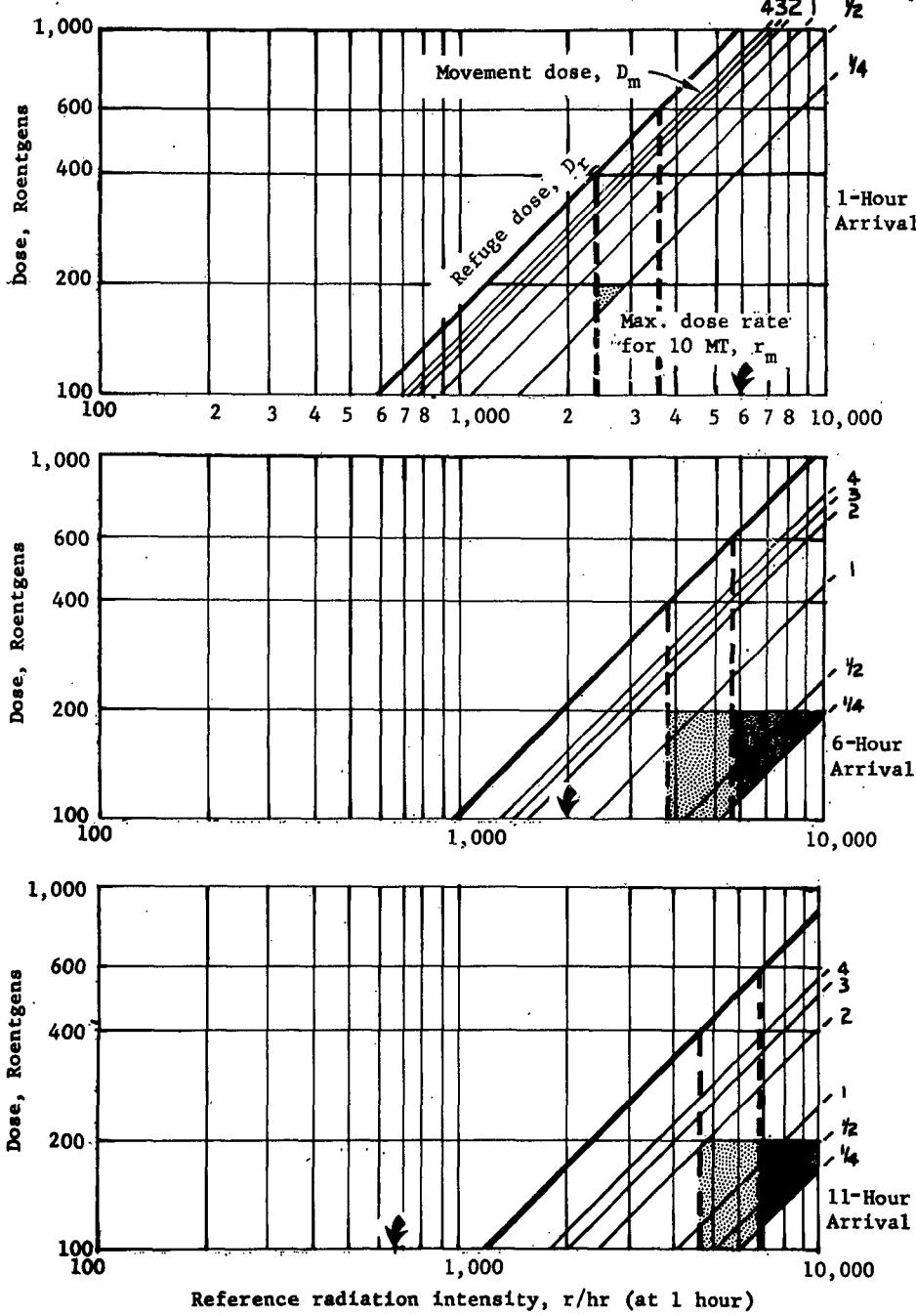


Figure 4. Remedial Movement and Refuge Exposures for  
Refuge Protection Factor of 20

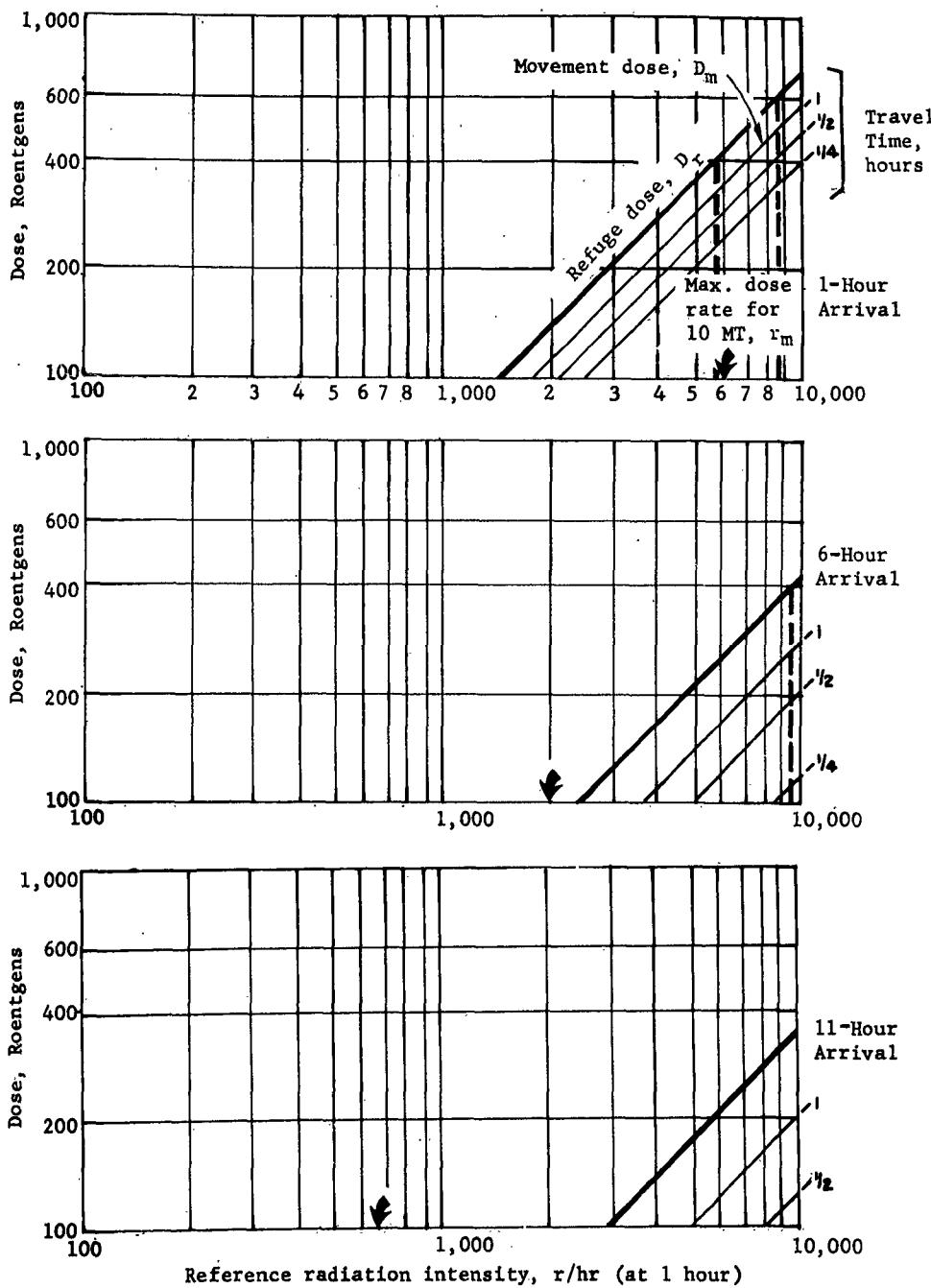


Figure 5. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 50

2. If remedial movement is implemented for the 350 r/hr case (i.e., 400r refuge dose), and the travel time is estimated to be 3 hours, the total remedial movement dose would be about 190r.
3. If the reference intensity were 520 r/hr (i.e., 600r refuge dose), the travel time would have to be 1.3 hours or less, to keep the exposure during movement below 200r.

In the judgement of the author, the shaded areas on the figures indicate the primary payoff conditions.

1. The darkly shaded area indicates conditions in which a refuge dose of 600r or greater (i.e., high mortality) is reduced to a remedial movement dose of 200r or less. On figure 1, Arrival Time of One Hour, the travel time cannot exceed 1.3 hours if the above payoff condition is to be obtained.
2. The lightly shaded area indicates conditions where potentially high mortality exposures in the shelter are reduced to 200r or less by remedial movement. In the case on figure 1, travel time must be about 3.3 hours or less.

Obviously, other payoff conditions exist. However, the ones chosen appear to be the ones deserving first priority.

Arrowheads are also shown on the figures indicating "Maximum Dose Rate for 10 MT." These have been inserted to indicate the order of magnitude of the maximum reference intensity that might be associated with the various arrival times. This information was derived from Pugh and Galliano<sup>6/</sup> which tabulates the maximum downwind extent (in miles) of specified reference radiation dose rates. These values are given as functions of weapon yield, wind velocity, and effective wind shear. The downwind extent of various radiation intensities for an effective shear of 0.1 knot (per 1000-foot altitude) was plotted on figure 6. A greater shear produces lesser reference intensities at any given distance and wind velocity. The plotted values are related to a 100 percent

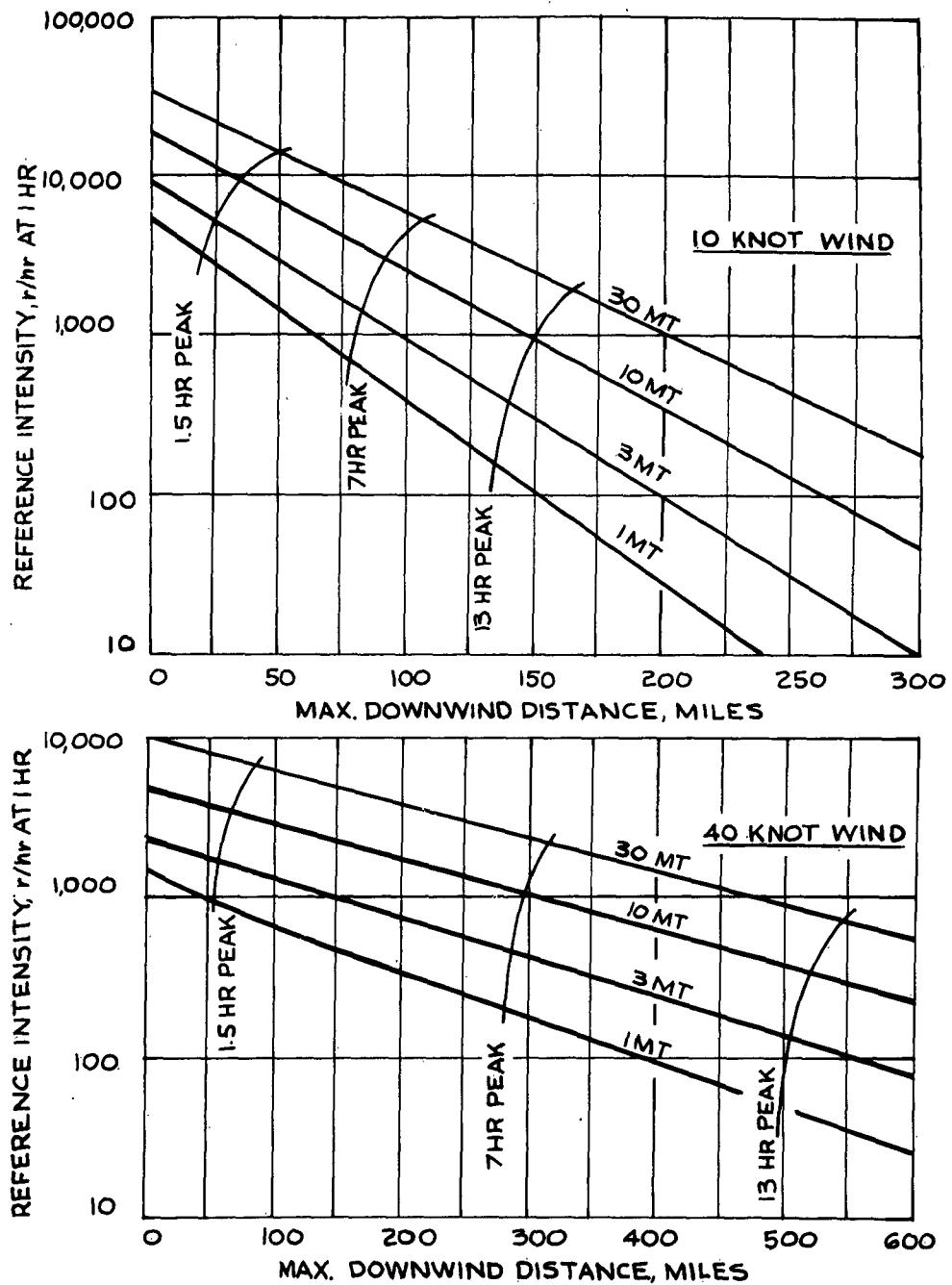


Figure 6. Maximum Possible Reference Intensities Appropriate to Different Arrival Times, Yields, and Wind Velocities

fission yield so that suitable corrections should be made for more realistic devices. Also plotted on figure 6 are the downwind distances relatable to the assumed times of peak intensity (essentially time of arrival of fallout) and the assumed wind velocities. The distances for the same arrival time also vary with yield because of the differences in initial cloud diameter. The intersections of the plotted curves indicate on the ordinate the maximum reference intensity related to a certain arrival time, weapon yield, and wind velocity. Maximum values occur with a 30-megaton yield, 10-knot wind, and effective fallout shear of 0.1 knot. Reasonable maximum values are assumed to be defined by a 10-megaton yield detonation, with two-thirds of the yield due to fission. On this basis, the maximum feasible reference intensities for different arrival times are as follows:

Maximum Feasible Reference Intensity, r/hr

<u>Arrival Time</u>	<u>10-MT detonation - 10-knot wind</u>	
	<u>100% fission</u>	<u>67% fission</u>
1 hr (1.5-hr peak)	9000	6000
6 hr (7-hr peak)	3000	2000
11 hr (13-hr peak)	1000	670

The maximum intensities tend to indicate limits of the problem for the later arrival times. For instance, figure 2 (protection factor = 6) for an 11-hour arrival indicates that refuge doses of greater than 200r may not occur. Because of the uncertain nature of this limit, it should be used only as a guide.

#### CONCLUSIONS

Within the limitations imposed by the conditions of the study, certain general conclusions can be drawn from inspection of the figures:

1. As might be expected, the maximum opportunities for payoff are related to lower protection factors, i.e., less than 10.

2. Maximum payoff conditions are related to fallout arriving earlier than eleven hours.
3. Maximum payoff conditions generally involve reference radiation intensities of 350 r/hr or greater, with the upper limit of about 2000 r/hr.
4. For 1-hour arrivals, the maximum allowable travel time for maximum payoff is about 1.3 hours.

#### RECOMMENDATIONS

The above conclusions indicate that remedial movement is technically feasible in a variety of radiological situations. However, additional studies are needed to determine the impact of fallout arrivals between one and six hours.

The development of simple decision procedures and operational planning guides are also needed to determine the operational practicality of remedial movement.

## LIST OF REFERENCES

1. California Disaster Office, Planning Guide, Radiological Defense Annex, pp 1-4.
2. National Committee on Radiation Protection and Measurement, Exposure to Radiation in an Emergency, Report No. 29, January 1962.
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5. Doughty, D. J. and D. C. Kleinecke, A Simplified Time-Dependent Gamma-Ray Spectrum for Fallout. University of California, Institute of Engineering Research, Series 2, Issue 26, 15 August 1959.
6. Pugh, G. E. and R. J. Galliano. An Analytic Model of Close-in Deposition of Fallout for Use in Operational-Type Studies, Weapons Systems Evaluation Group, WSEG Research Memorandum No. 10, 15 October 1959.

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